Modeling Logging While Drilling Systems at Low Frequencies Using the Finite Difference Time Domain (FDTD)

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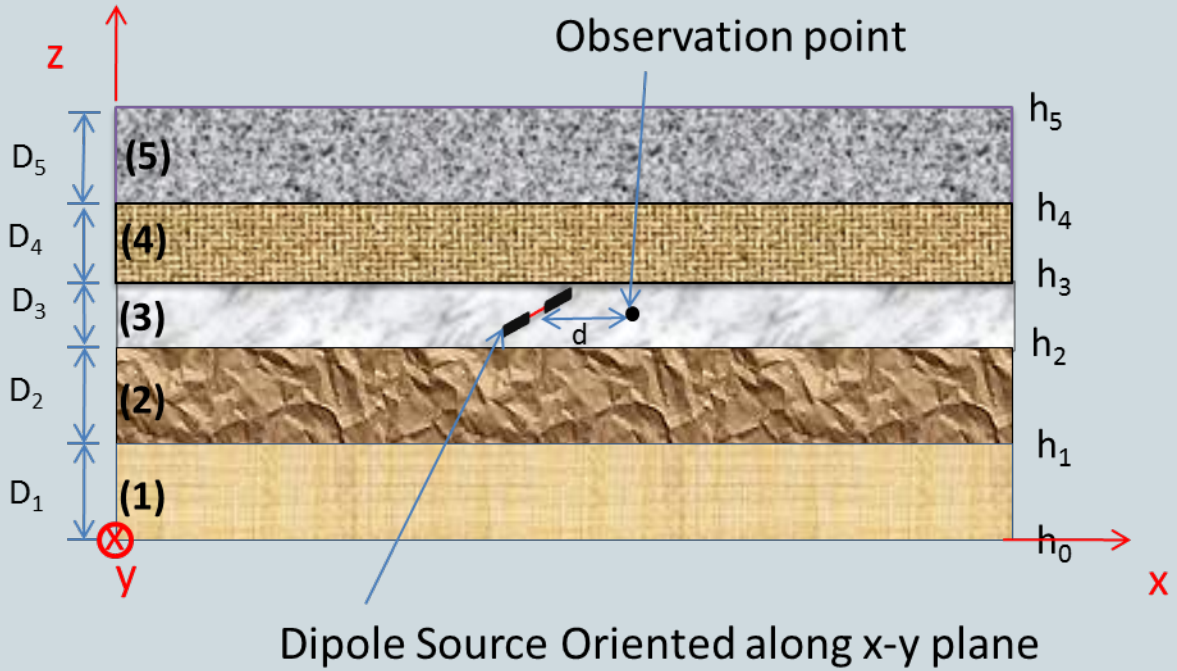
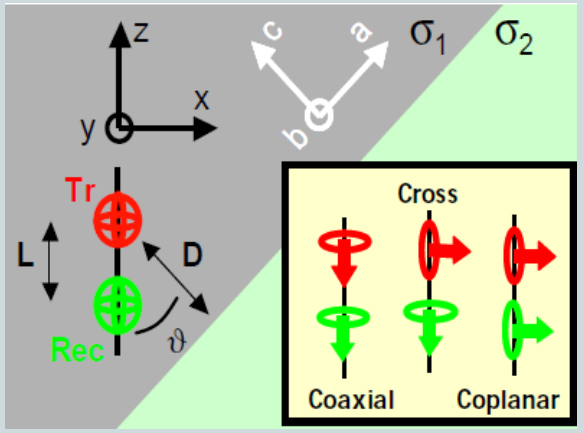
Time Domain Measurements in Well Logging



Dipole Source Oriented along x-y plane



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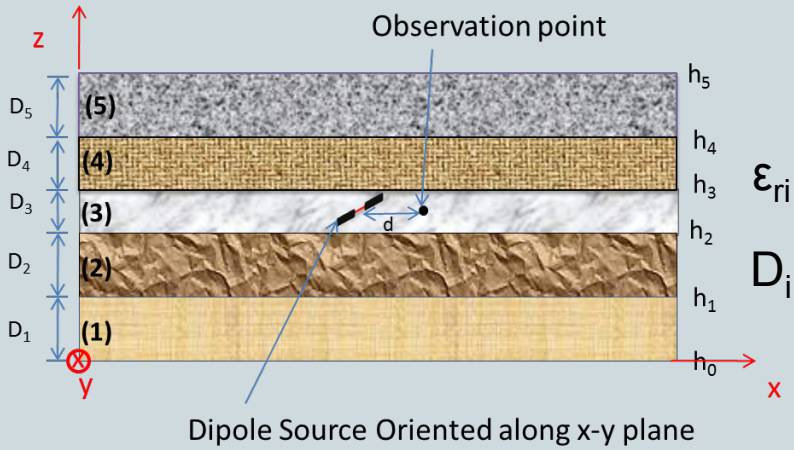
Three orthogonal sources make up the transmitter and the receiver

i^{th} layer has ε_{ri} = 10-50, σ_{ri} =.01-1 S/m and thickness D_i = 2-20 ft

Observation point located at a distance d=2 ft from source

Bandwidth of source 1KHz to 1MHz

Material Parameters of the Layered Medium



ε_{ri} = 10-50, σ_{ri} =.01-1 S/m

D_i = 2-20 ft (.6096 – 6.096 m)

λo (1MHz) = 300 m

λo (1KHz) = 300 km

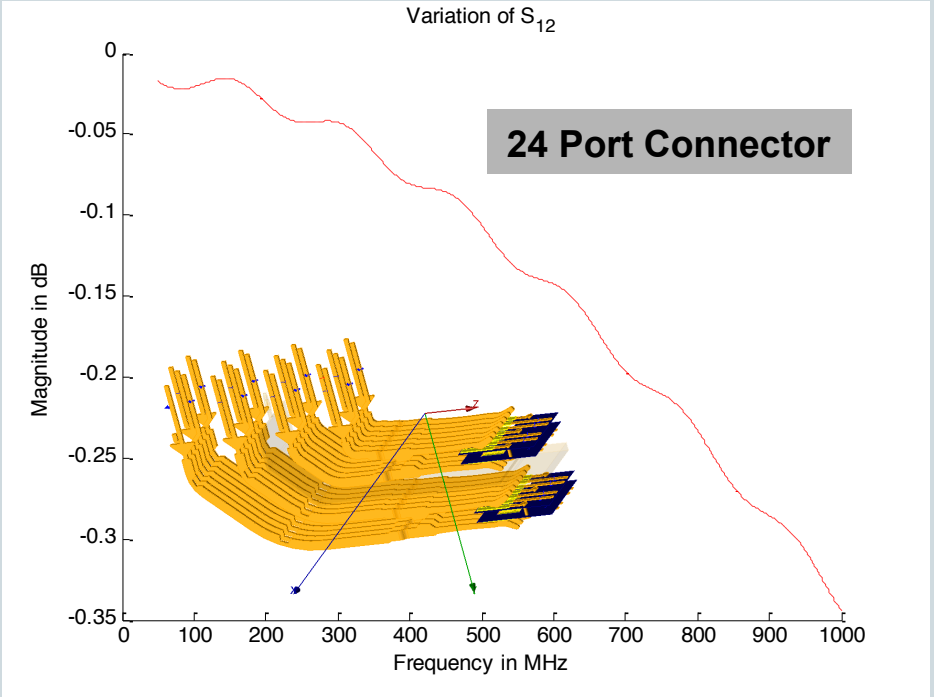
Quasi Static Solution Not Accurate because Real and Imaginary parts of ε_{ri} are comparable, or imaginary part can be much higher than the real part .

$Re(\varepsilon_{ri})$	σ_{ri} (S/m)	$Im(\varepsilon_{ri})$ (1 KHz)	$Im(\varepsilon_{ri})$ (1 MHz)
10.00	0.01	179750.00	179.75
10.00	1.00	17975000.00	17975.00
50.00	0.01	179750.00	179.75
50.00	1.00	17975000.00	17975.00

Low Frequency Breakdown

Conventional FDTD:

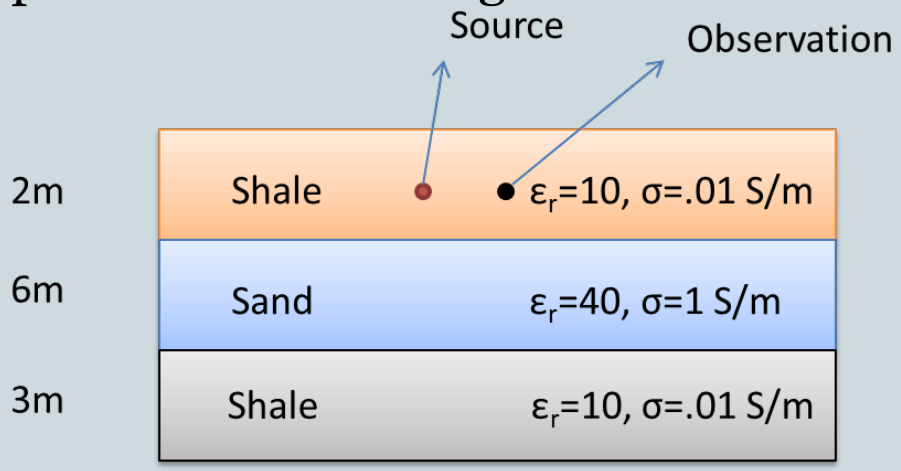
- By using Gaussian pulse excitation, accurate high frequency results can be generated (most of the time > 1GHz)
- For low frequencies, the results often show wiggles and also require a large number of time steps.



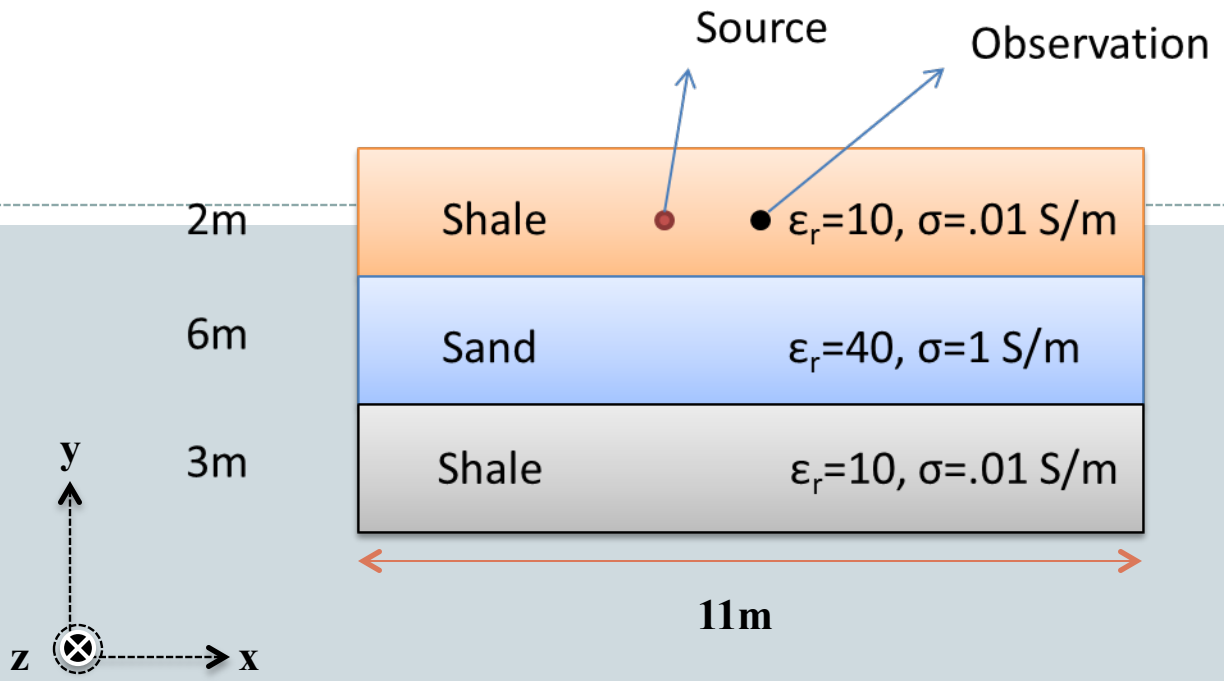
Frequency	10 MHz	1 MHz	1 Hz
Time Steps in millions	0.7	7	70

Low Frequency Breakdown

- The absorbing boundary conditions become ***less effective*** at lower frequencies and cannot absorb the evanescent part of the fields. In addition, because the size of the source is very small compared to the wavelength, a ***very fine mesh*** has to be used to model the source. And in FDTD the problem complexity increases 16 fold when the mesh size is halved, which is very expensive. The current problem requires ***250 GB*** of memory and has to be run for nearly ***100 million*** time steps to reach a convergent solution.



Sand Between Shale

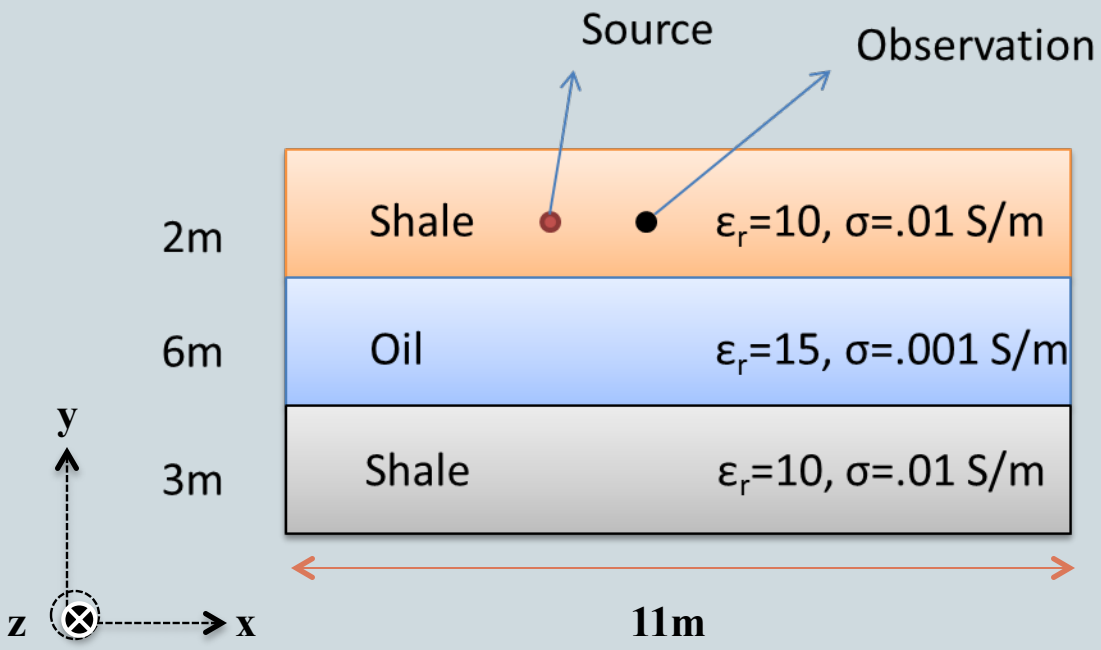


Freq. 1 KHz to 1 MHz

FDTD Mesh Size: λ/1500, λ @ 1 MHz

A magnetic/electric dipole is used for this simulation.
The observation point is at a distance of 1m from the source.
Number of time steps: 10000

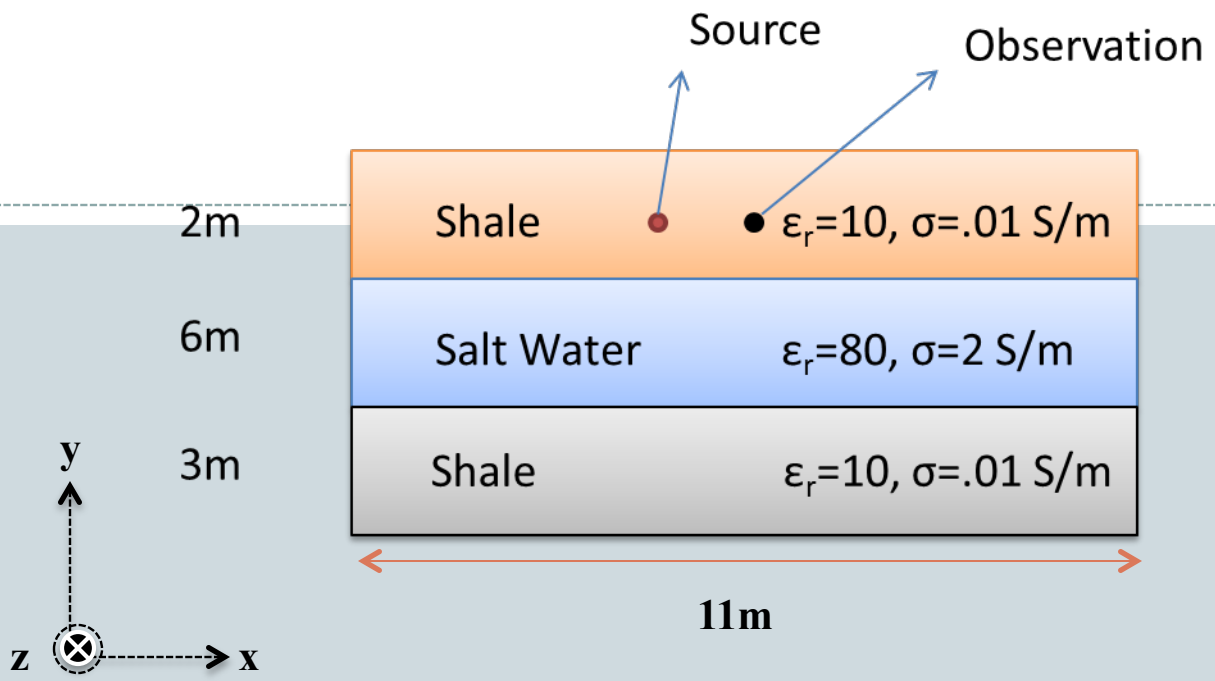
Oil Between Shale



Freq 1 KHz to 1 MHz

A magnetic/electric dipole is used for this simulation.
The observation point is at a distance of 1m from the source.
Number of time steps: 10000

Water Between Shale



FDTD Mesh Size: λ/1500, λ @ 1 MHz

Freq 1 KHz to 1 MHz

A magnetic/electric dipole is used for this simulation.
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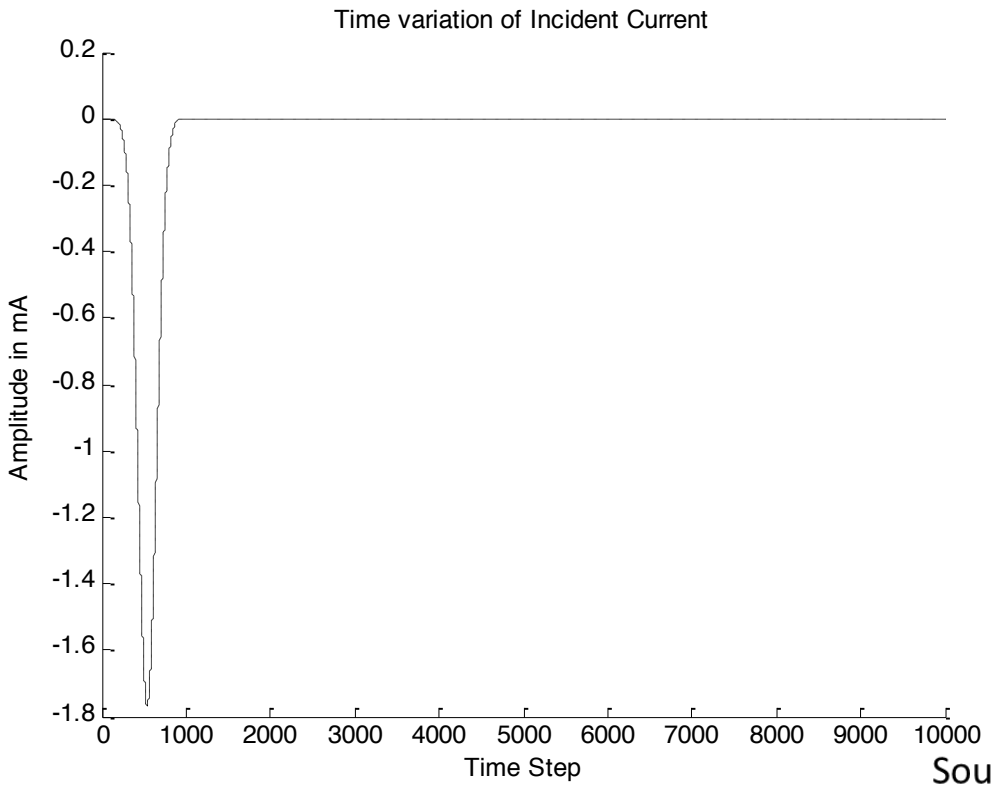
Number of time steps: 10000

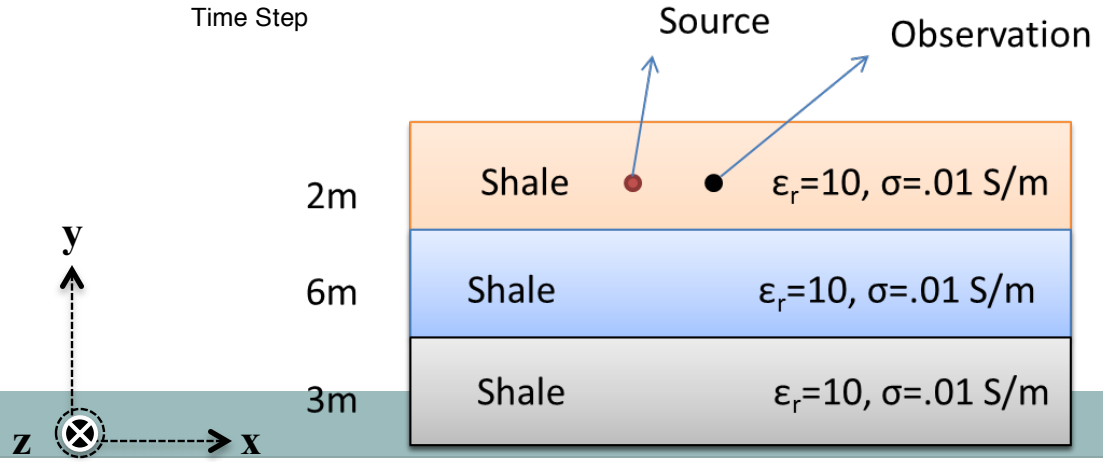
X-Oriented Magnetic Dipole Source Modeling by Using FDTD

Excitation is a Gaussian Pulse with 3 dB cutoff at 1 MHz
A PEC Loop of radius 0.2m (λ/1500, λ @ 1 MHz) is used for transmitting and receiving antenna.

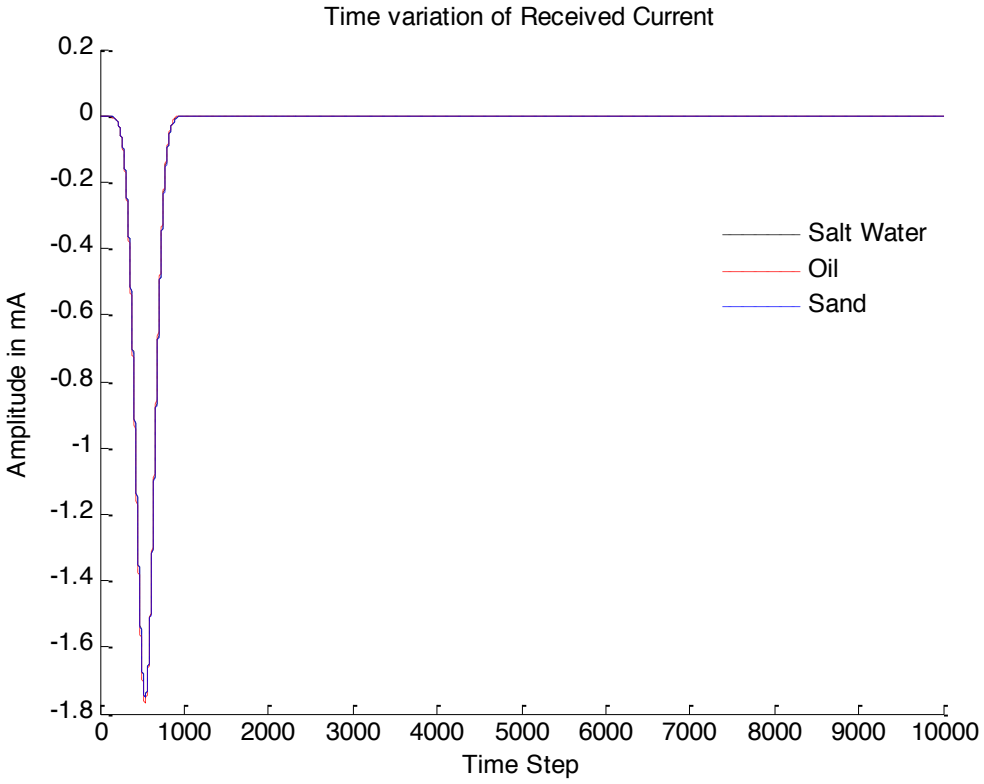
Incident Time Signature of Loop Current (x-oriented magnetic dipole)



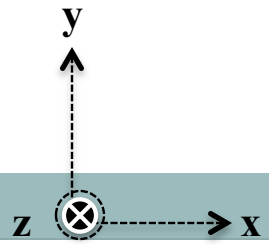
Incident means the time signature of the field at the receiver when a Gaussian pulse is transmitted and the assembly is placed in a homogeneous medium (shale).

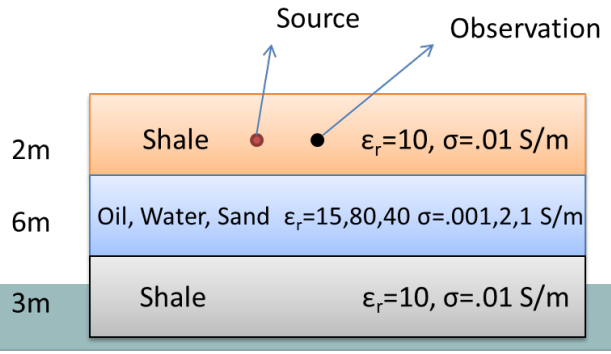


Received Time Signature of Loop Current (x-oriented magnetic dipole)

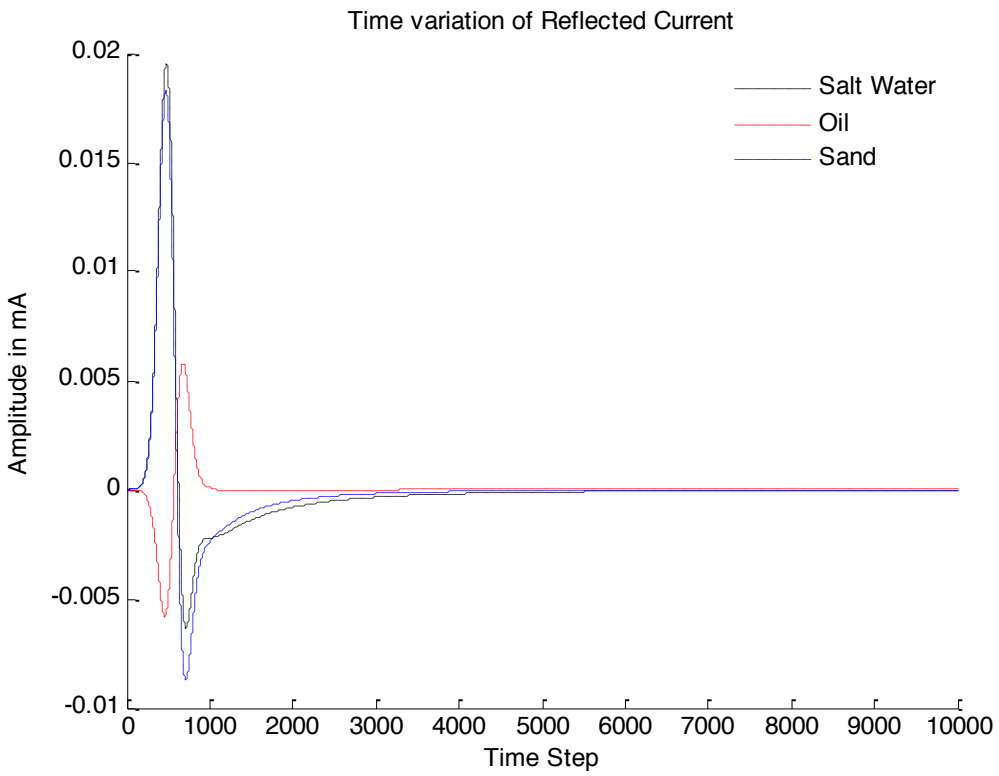


Oil or Salt water or Sand are not distinguishable from total field. Therefore, compute reflected field.





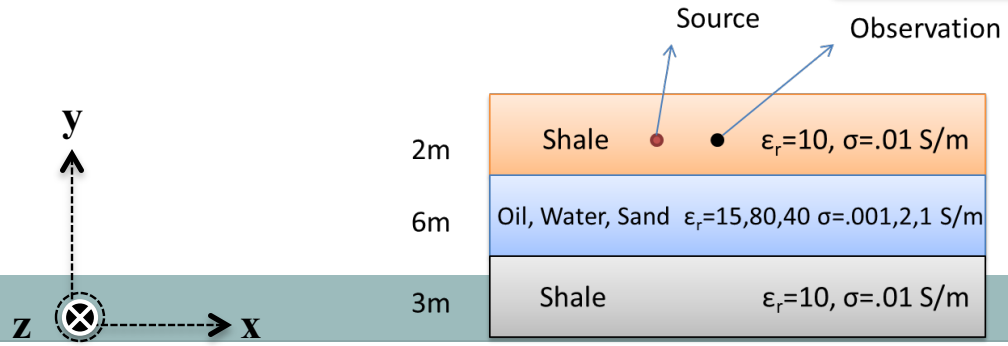
Reflected Time Signature of Loop Current (x-oriented magnetic dipole)



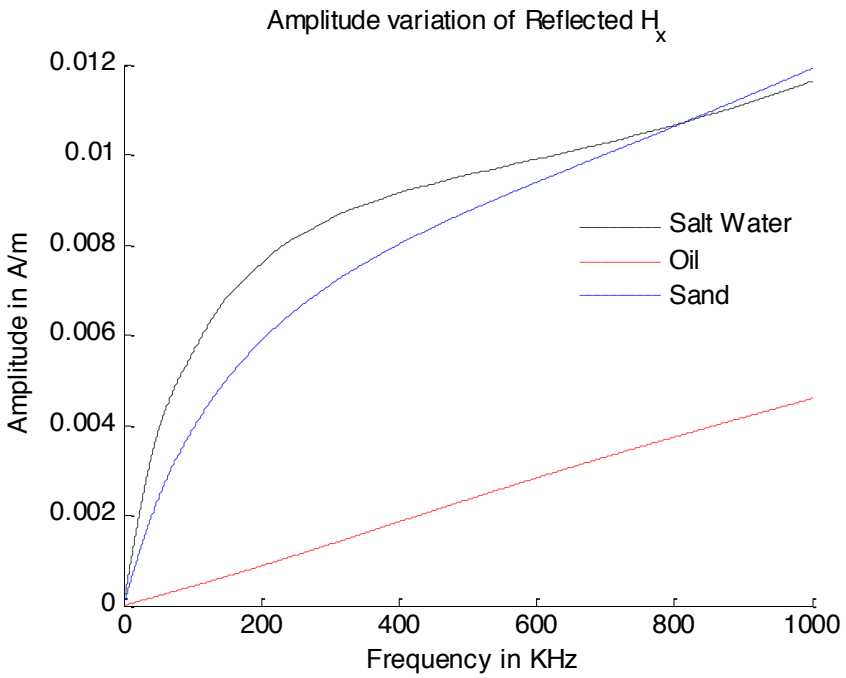
Reflected = Total - Incident

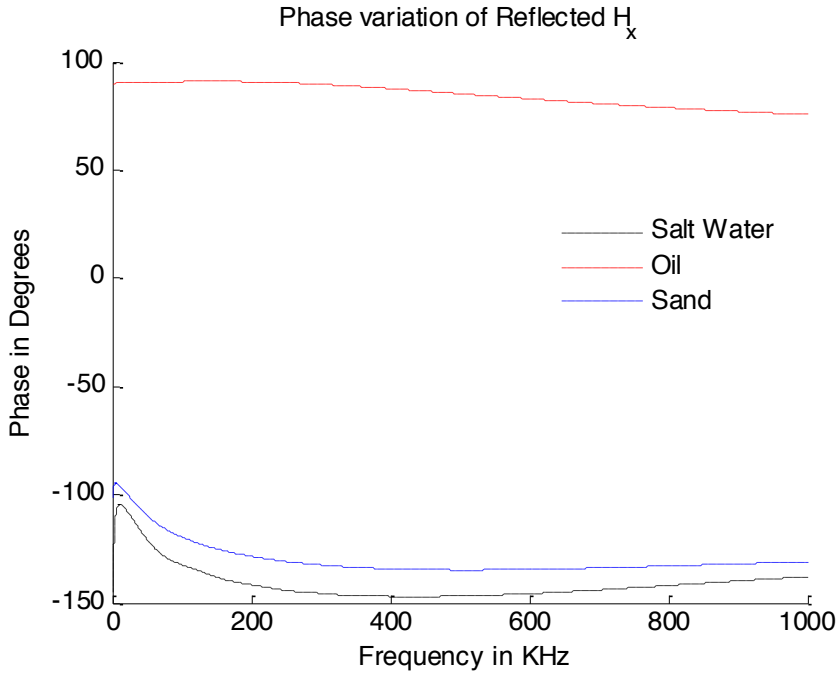
Salt water shale interface shows higher reflection compared to sand shale interface, which shows higher reflection compared to oil shale interface

Reflected field shows a phase change of 180° w.r.t the indident field if conductivity of the middle layer is higher than shale



Frequency Variation of Reflected H_x (x-oriented magnetic dipole)

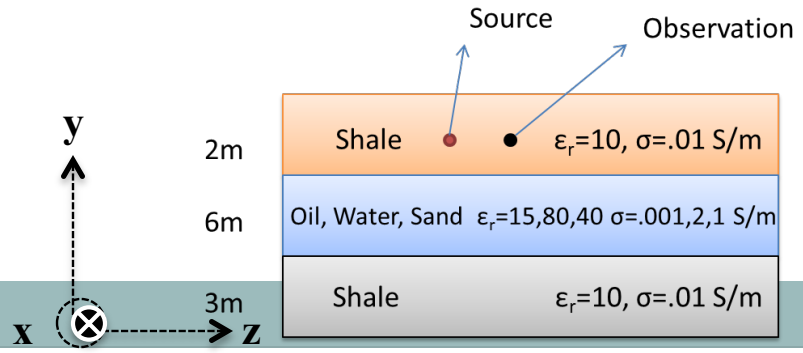




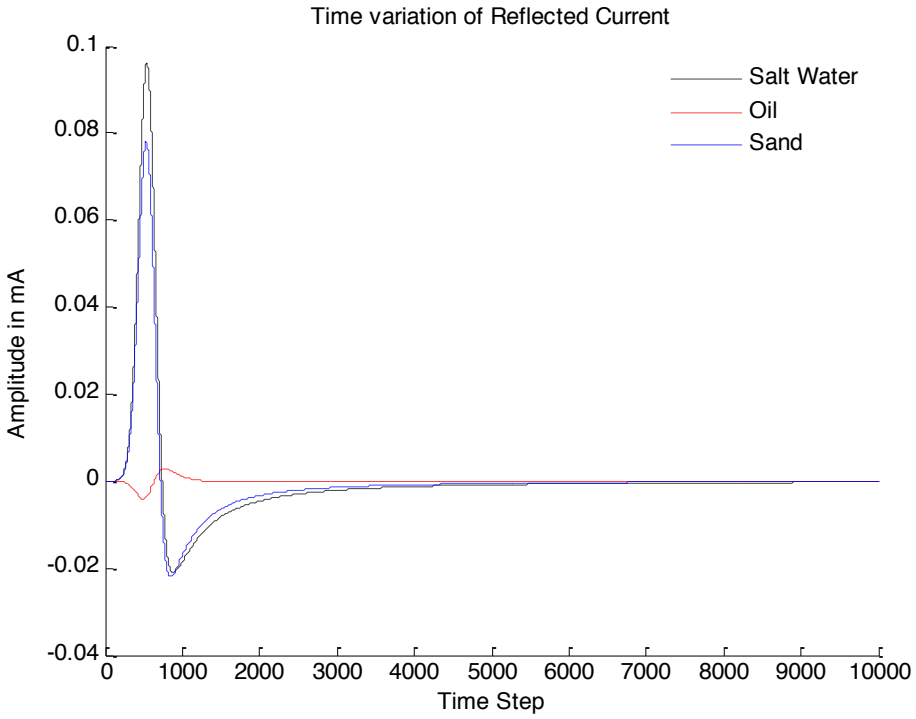
Amplitude

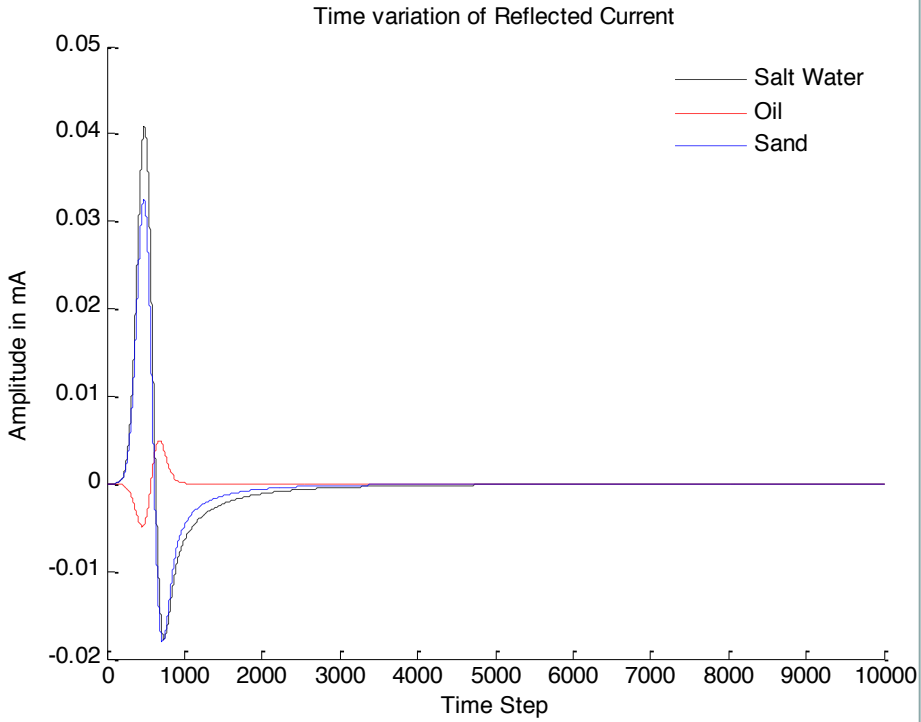
Phase

Salt water shale interface shows higher reflection compared to oil shale interface as expected

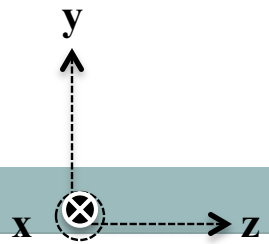


Reflected Time Signatures (magnetic dipoles)

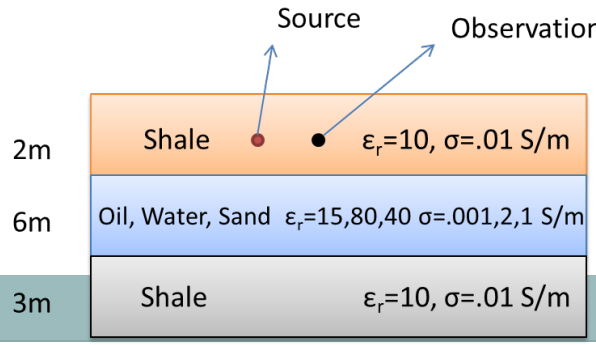




y-oriented magnetic dipole



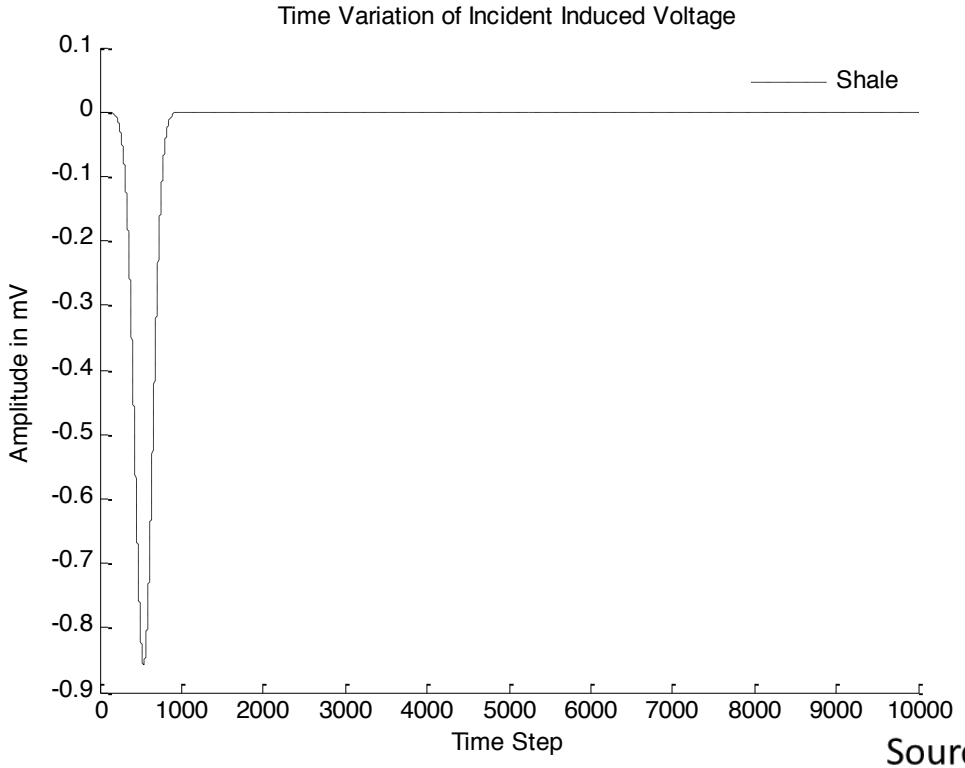
z-oriented magnetic dipole



Electric Dipole Source Modeling by Using FDTD

Excitation is a Gaussian Pulse with 3 dB cutoff at 1 MHz
Electric Dipole of Length 0.2m (λ/1500, λ @ 1 MHz) is used for transmitting and receiving antenna.

Time Signature of Incident Voltage (x-oriented electric dipole)



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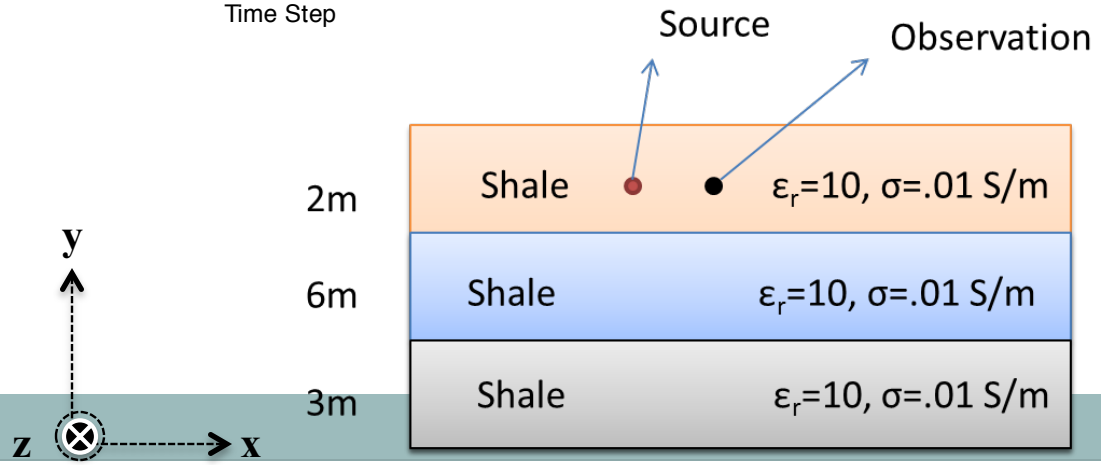
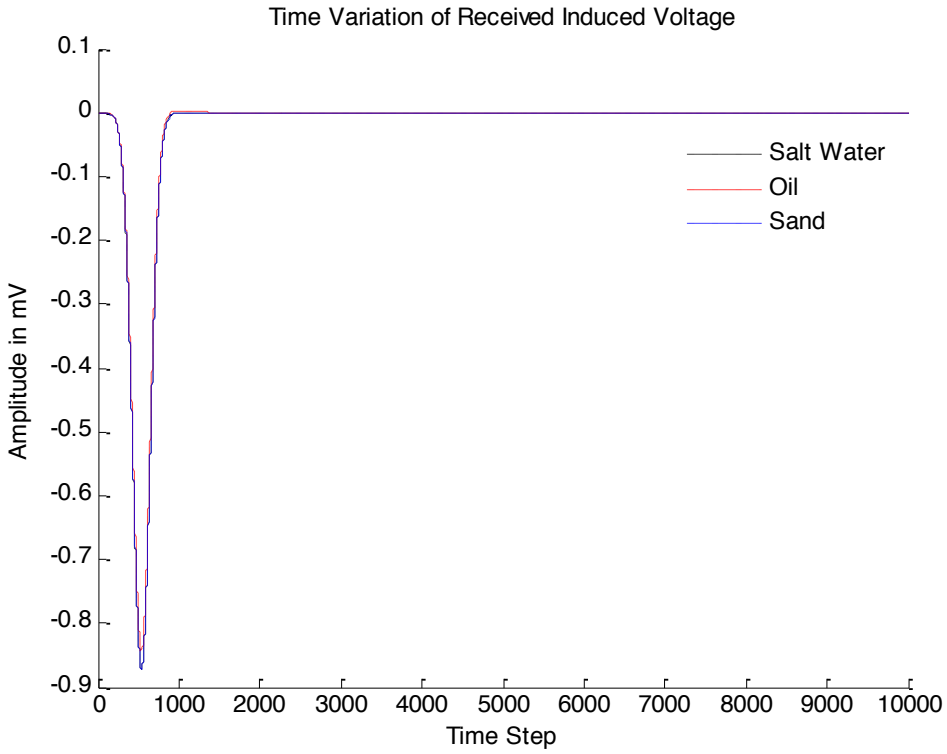


Total Time Signature of Received Induced Voltage (x-oriented electric dipole)



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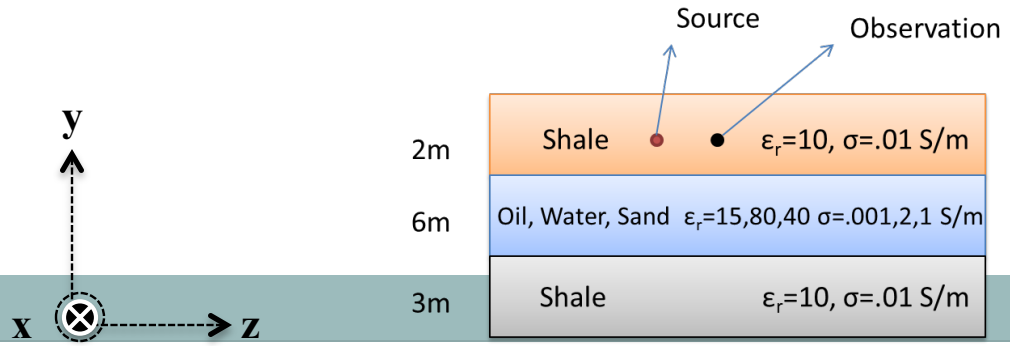
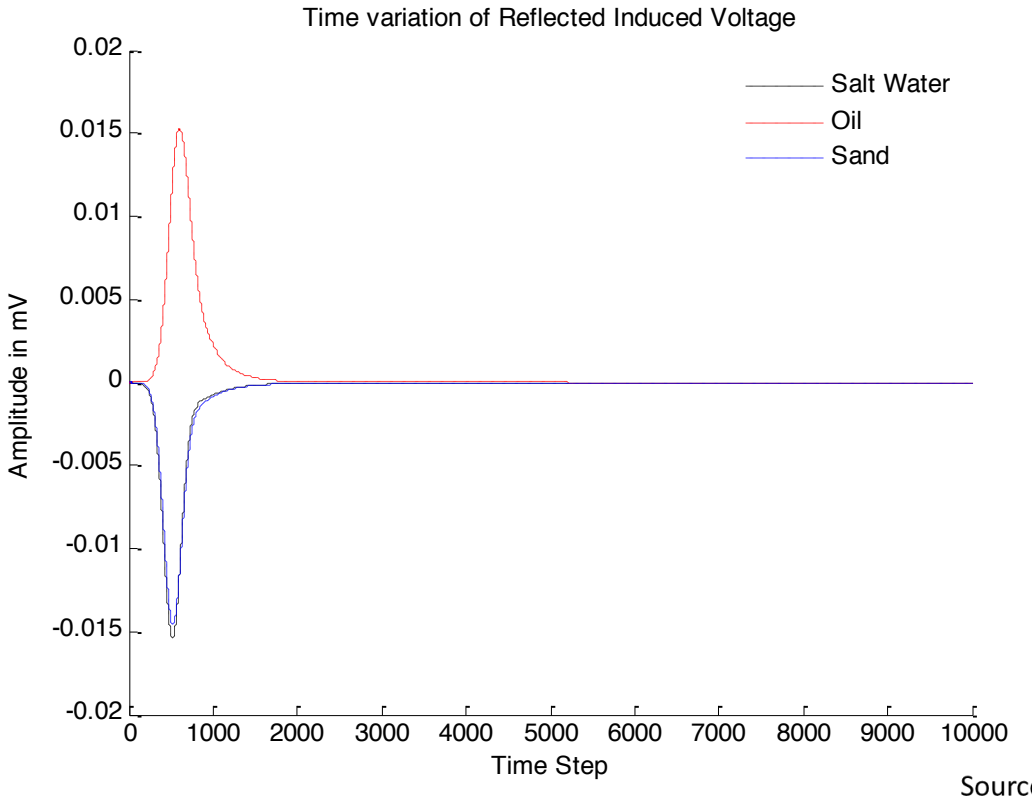


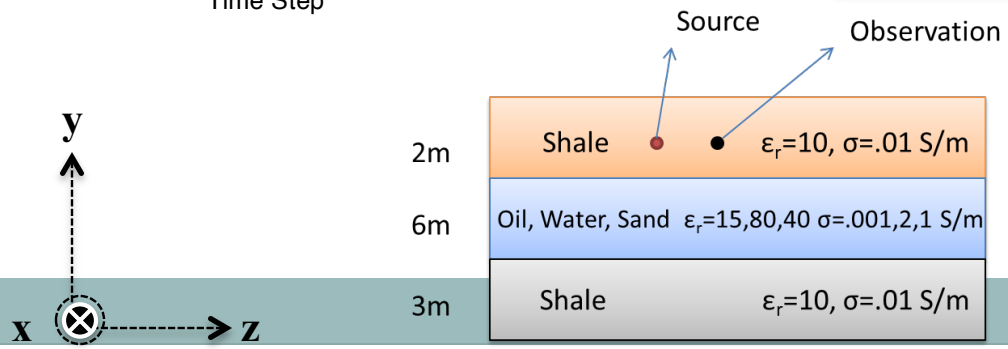
Time Signature of Reflected Induced Voltage (x-oriented electric dipole)



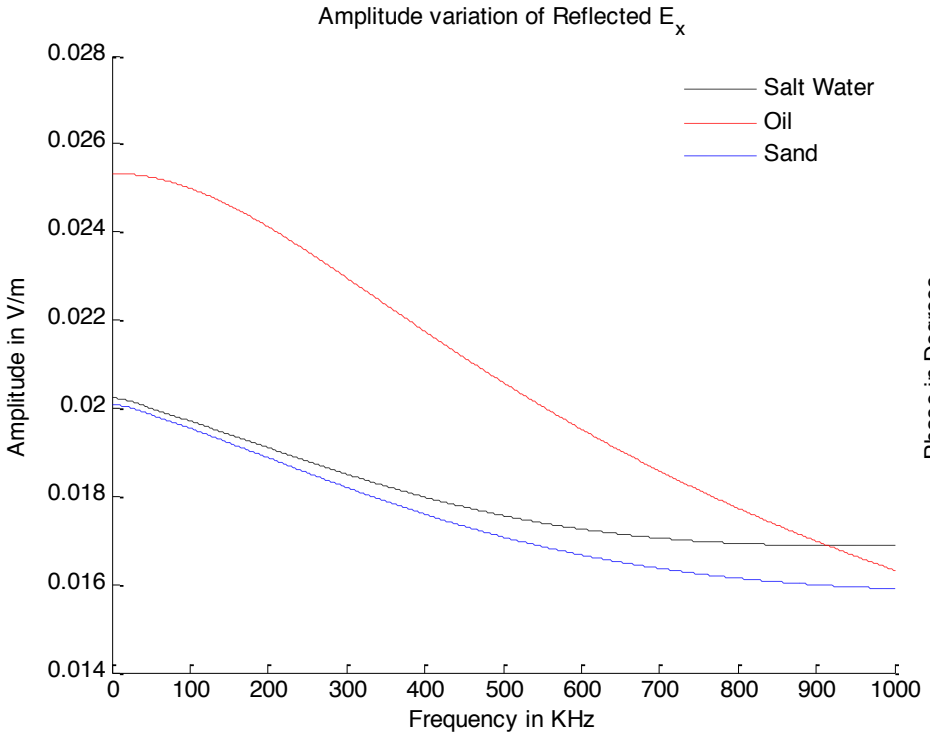
Reflected = Total - Incident

Conclusion: Use Magnetic Dipole instead of Electric Dipole

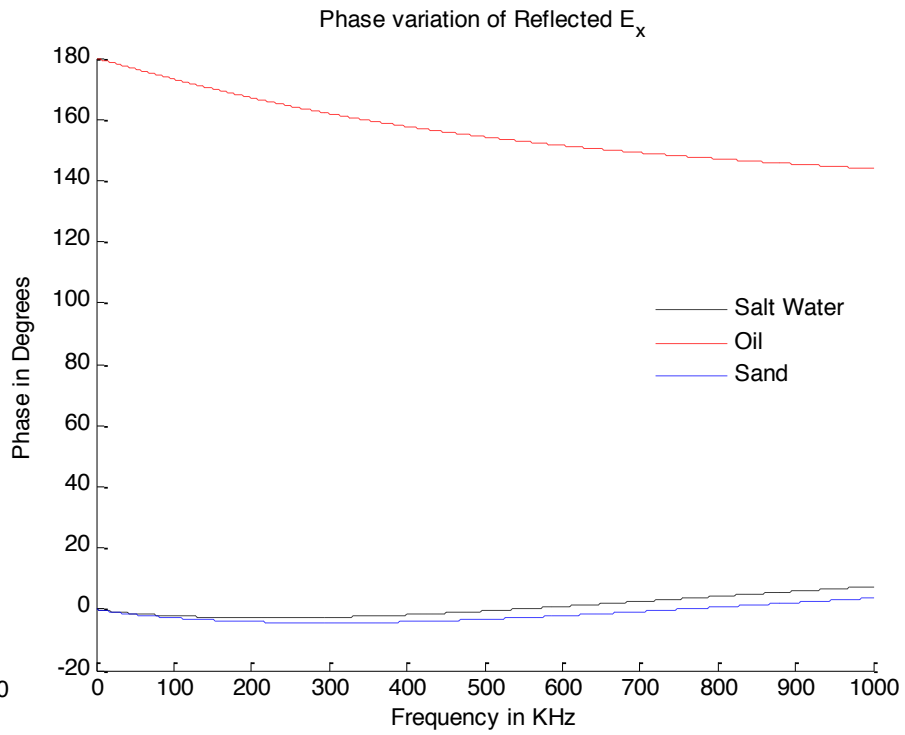
Reflected field shows a phase change of 180° w.r.t the incident field if conductivity of the middle layer is higher than shale



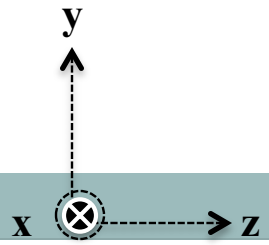
Frequency Variation of Reflected E_x (x-oriented electric dipole)

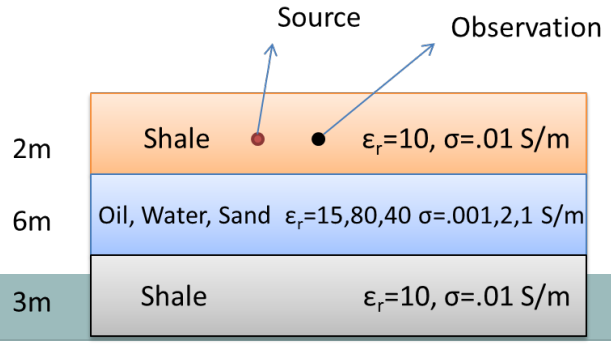


Amplitude

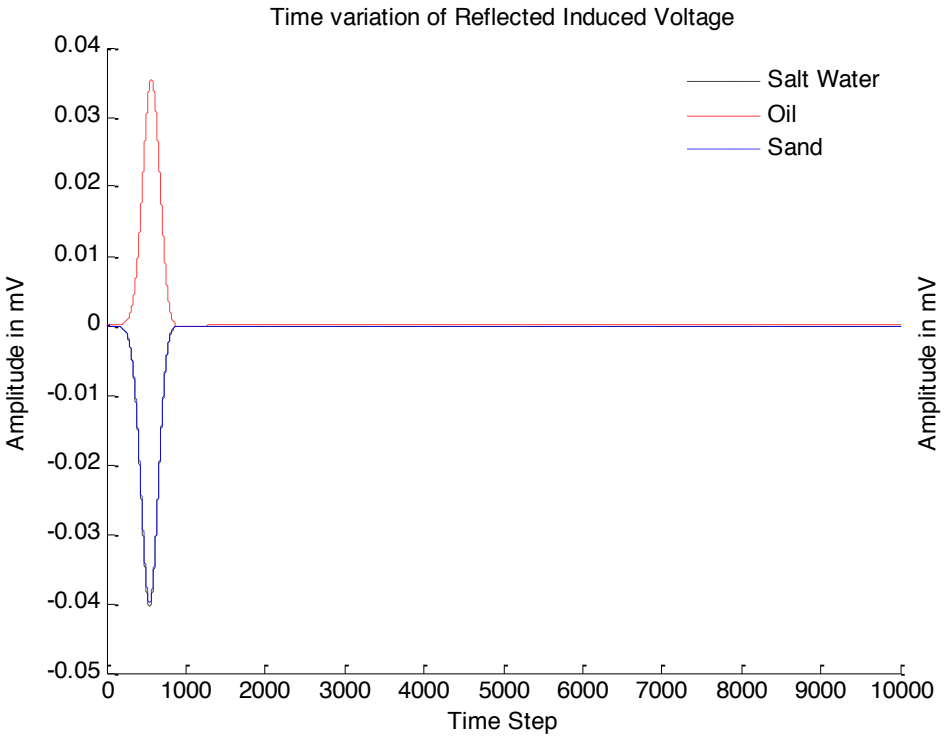


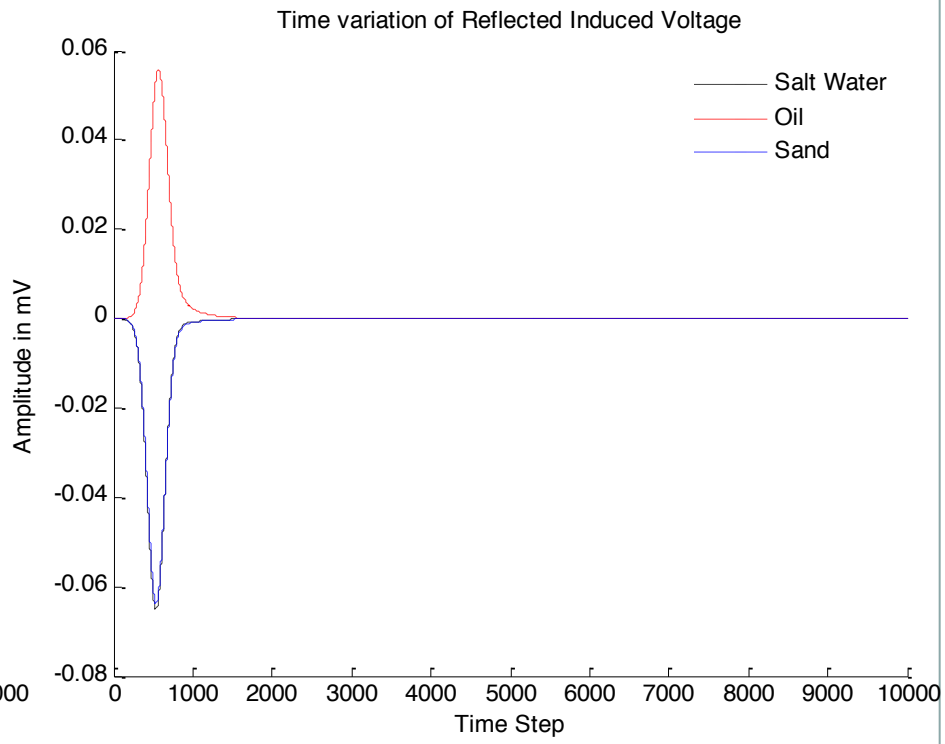
Phase



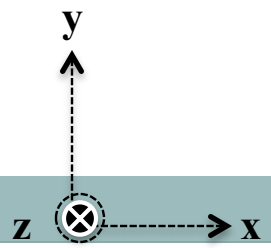


Reflected Time Signatures (electric dipoles)

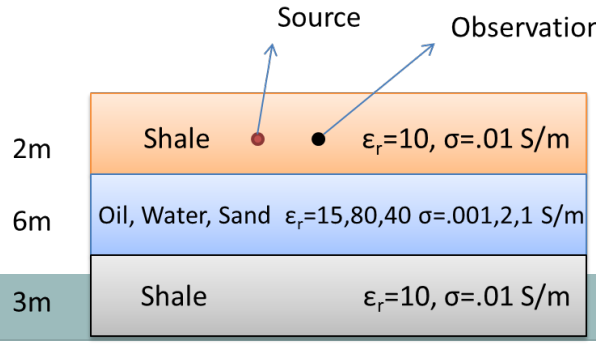




y-oriented electric dipole

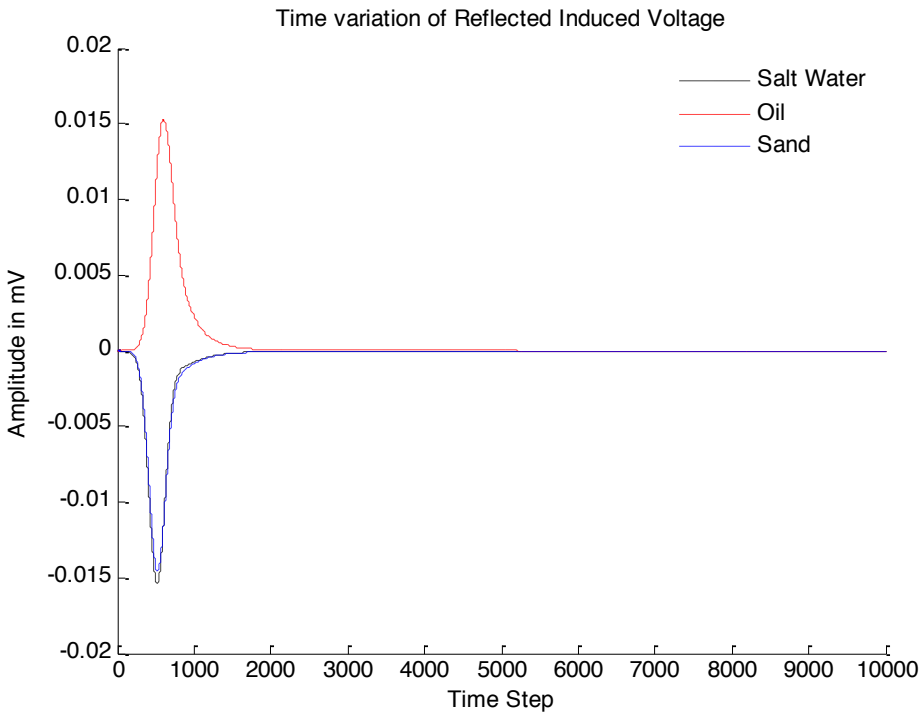


z-oriented electric dipole

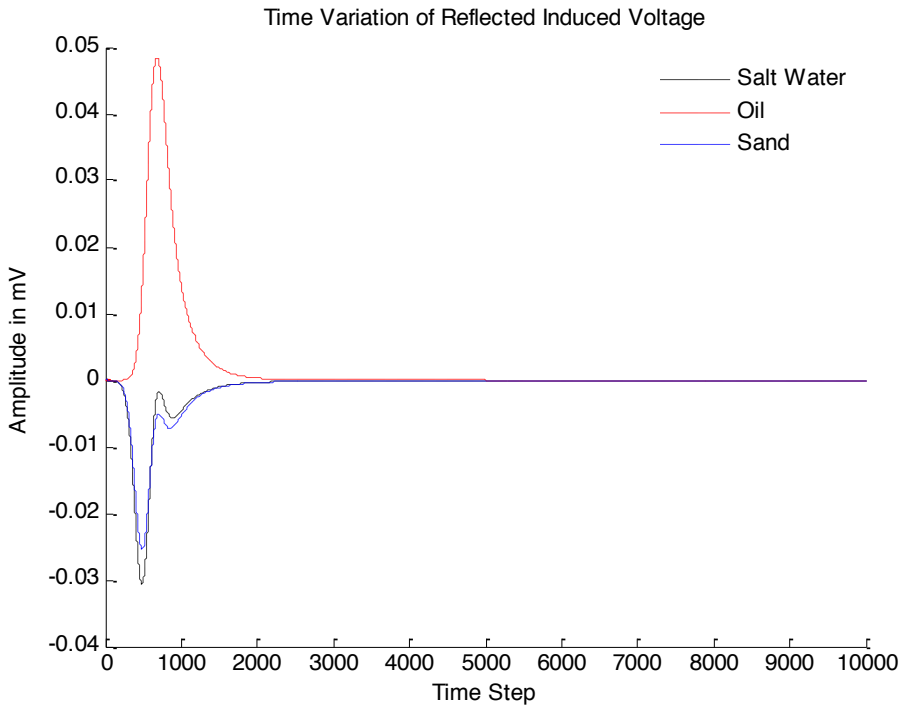


Conclusion: Use Magnetic Dipole instead of Electric Dipole

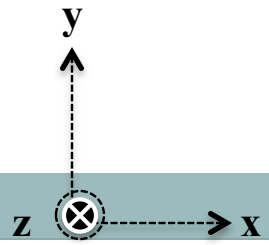
Reflected Time Signatures (for different lengths of electric dipoles)

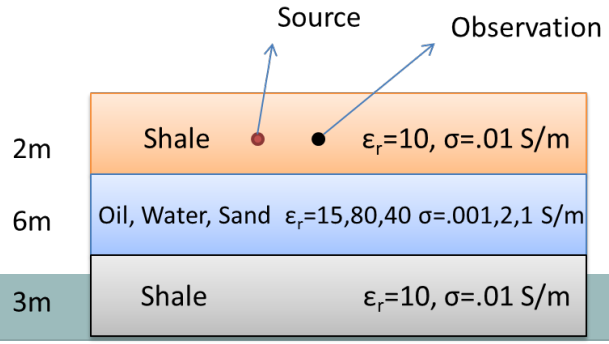


0.2 m (λ/1500) electric dipole



0.4 m (λ/750) electric dipole





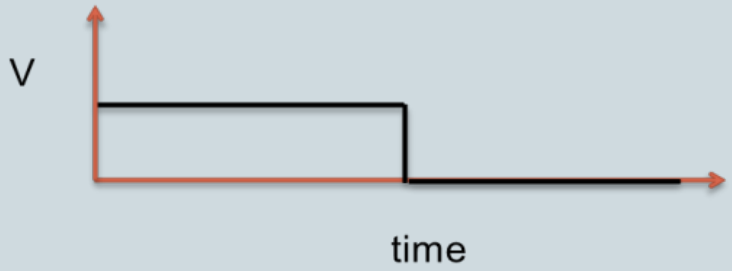
Conclusion: Use Magnetic Dipole instead of Electric Dipole

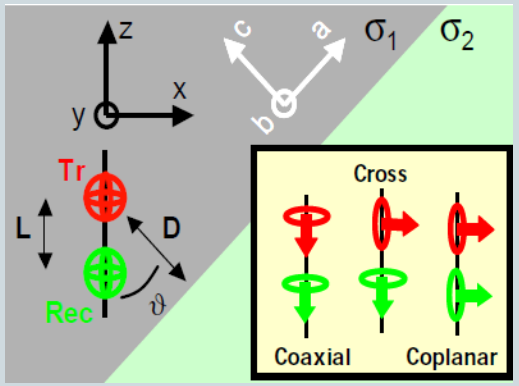
Conclusions

- It is preferable to use a magnetic dipole instead of an electric dipole, since the reflections from the interface depend on the relative permittivities and conductivities of the layers.
- Oil trapped in-between shale shows lower magnitude of reflected magnetic field as compared to water trapped in between shale or sand trapped in between shale because the difference between the permittivities and conductivities of water or sand and shale is much higher than that between shale and oil.
- Depth of the fracture can be calculated from the scattering values in an efficient way using Dipole Moment Approach.

Future Work

- Evaluate the fields analytically by using the scalar and vector potential information to validate the FDTD results.
- Investigate three orthogonal magnetic dipole oriented at an angle with the layered medium to evaluate the apparent dip angle (ν), distance D and conductivities of the layers by doing cross, coaxial and coplanar measurements, using a step excitation at the transmitting magnetic dipoles as shown in Figure below.





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Thank You!